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Capital Cost Targeting of Total Site Heat Recovery

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Exploiting heat recovery on Total Site level offers additional potential for energy saving through the central utility system. In the original Total Site Methodology (Klemeš et al., 1997) a single uniform ΔT_{min} specification was used. It is unrealistic to expect uniform ΔT_{min} for heat exchange for all site processes and also between processes and the utility system. The current work deals with the evaluation of the capital cost for the generation and use of site utilities (e.g. steam, hot water, cooling water), which enables the evaluation of the trade-off between heat recovery and capital cost targets for Total Sites, thus allowing to set optimal ΔT_{min} values for the various processes. The procedure involves the construction of Total Site Profiles and Site Utility Composite Curves and the further identification of the various utility generation and use regions at the profile-utility interfaces. This is followed by the identification of the relevant Enthalpy Intervals in the Balanced Composite Curves. A preliminary result for evaluation of heat recovery rate and capital cost can be obtained.

1. Introduction

Targeting capital and operational cost of Heat Exchanger Networks (HENs) was initially developed by Townsend and Linnhoff (1984) and further elaborated (Ahmad et al., 1990). A trade–off between the rate of heat recovery and the involved capital cost for an individual process, accepting a single ΔT_{min} specification has been described (Serna-González et al., 2007) and it still receives considerable attention (Serna-González and Ponce-Ortega, 2011). In a recent works (Varbanov et al., 2012; Klemeš and Varbanov, 2012) Total Site heat recovery targeting using multiple ΔT_{min} specifications for the site processes and process-utility interfaces has been explored. It is also possible to define and use the ΔT_{min} contributions of individual process streams in a process (Kravanja et al., 1997). The current work provides a procedure for determining the heat transfer area for meeting the targeted heat recovery on the Total Site. This can be used in further work for finding the optimal configuration of ΔT_{min} specifications for heat recovery inside the processes and between them through the utility system.

2. Methodology

A Total Site is a set of processes linked through a central utility system. The first step for Total Site targeting is to maximise the heat recovery within the processes. Total Site Profiles (TSPs) are then constructed to evaluate heat recovery potential between the processes through the utility system. The procedure is described next and illustrated in Figure 1.

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Step 1. Process heat recovery (Figure 1). The process-level utility targets and Grand Composite Curves (GCCs) are obtained using the Problem Table Algorithm (PTA). The heat transfer area at process level is determined by following equation (Smith, 2005) including only the process-to-process heat exchange:

$$A = \sum_{k} \frac{1}{\Delta T_{LM,k}} \cdot \left[\sum_{i}^{HOT\ \ STREAMS\ \ I} \frac{Q_{i,k}}{h_i} + \sum_{j}^{COLD\ \ STREAMS\ \ J} \frac{Q_{j,k}}{h_j} \right] \tag{1}$$

where the area is determined as a sum of contributions the streams in each enthalpy interval *k* and then summed up. After obtaining GCC the segments for building the Total Site can be identified.

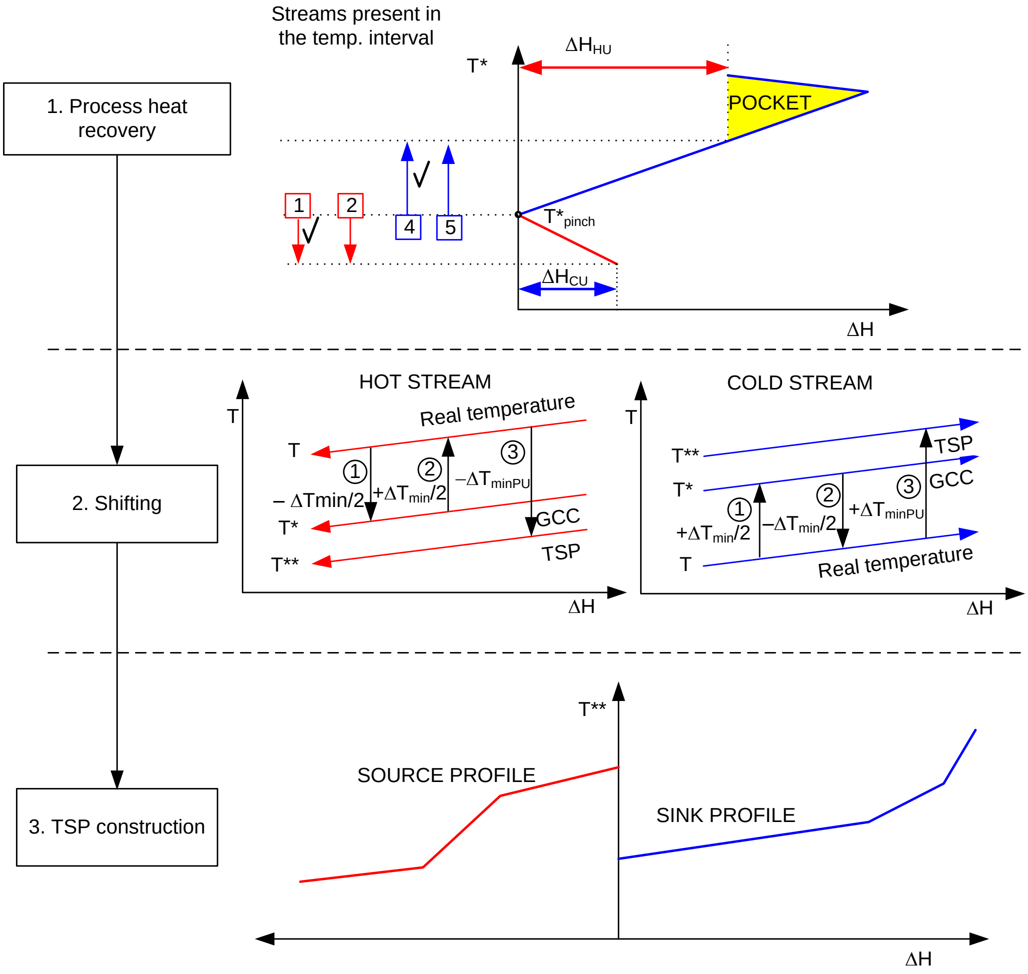


Figure 1: Constructing TSPs

Step 2. Shifting (Figure 1). In this step the segments identified at the previous step are shifted using the procedure by Varbanov et al. (2011), using individual ΔT_{min} specifications for heat exchange between process streams as well as between process streams and utility – for each of the site processes. Two shifts are performed for each GCC segment: (i) Back to the process stream real temperatures and then (ii) Forward by ΔT_{minPU}, which is the minimum temperature difference required for a feasible heat exchange between process streams and the utility.

Step 3. TSP construction (Figure 1). Using the shifted segments, the construction of TSP proceeds as in the original methodology by Klemeš et al. (1997). A numerical procedure suggested by Liew at al (2012) can be beneficially used. In constructing the diagram of the TSP (Figure 2), the heat source segments from process GCCs are combined on the left hand side of the Y–axis, while the heat sink segments – on the right hand side. As a result, the constructed diagram consists of two parts. On the left-hand side is the Heat Source Profile and on the right-hand part is the Heat Sink Profile. In this way the problem is partitioned into utility generation (Site Source Composite Curve) and utility use (Site Sink Composite Curve). Heat recovery can be performed through intermediate utilities. The Site Utility Composite Curves (SUCC) are constructed to evaluate the maximum site heat recovery. The combination of TSP and SUCC are used to estimate the heat transfer area required for utility generation and use. This is performed by forming Enthalpy Intervals, as illustrated in Figure 2 – selecting the enthalpy coordinates corresponding to the changes in the slopes of the Site Profiles and the Site Composite Curves.

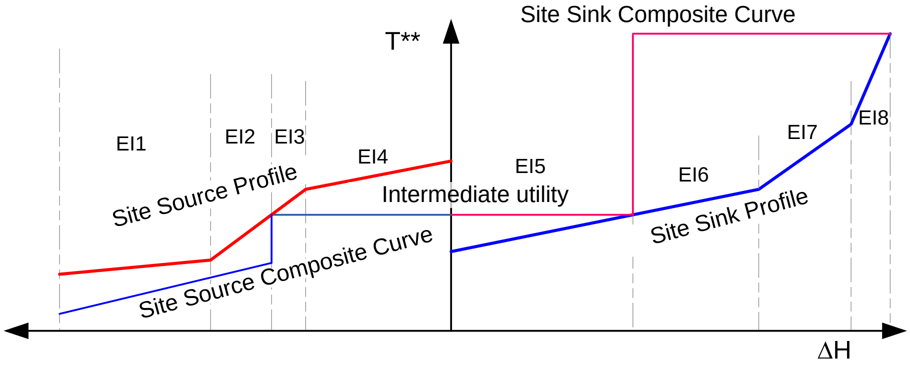
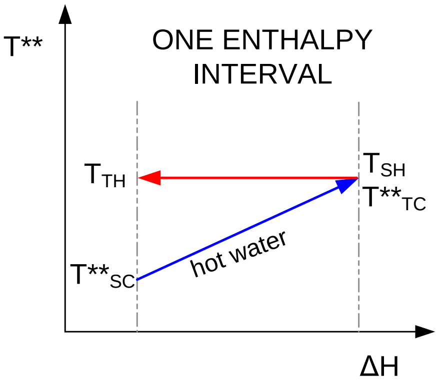


Figure 2: TSP with EI

Following the chosen area estimation approach (Smith, 2005), the heat exchange areas are determined in each EI using the general equation for heat transfer area evaluation (Figure 3). In the TSP plot, the utilities are represented at their real temperatures while the Site Profiles are at temperatures shifted by whole ΔT_{minPU} with respect to the initial process streams.



$$A = \frac{1}{\Delta T_{LM}} \cdot \left[\sum_{i}^{HOT\ STREAMS\ I} \frac{Q_i}{h_i} + \sum_{j}^{COLD\ STREAMS\ J} \frac{Q_j}{h_j} \right]$$

$$\Delta T_{LM} = \frac{(T_{SH} - T_{TC}) - (T_{TH} - T_{SC})}{\ln \frac{(T_{SH} - T_{TC})}{(T_{TH} - T_{SC})}}$$

Figure 3: Determining the heat transfer area in one EI

When the profiles for the process heat source and the hot water generation in Figure 3 touch each other they still have sufficient temperature difference equal to ΔT_{min}. Therefore, when determining the heat transfer area, the temperatures of the TSP segments are shifted back to their real temperatures. To determine the overall area for heat transfer between utility and process stream the areas from each EIs are summed up.

3. Case study

3.1 Input data

The input data for the case study are listed in Table 1. A Total site with two processes (A and B) is considered, each of them having three process streams.

Table 1: Input data for the case study

Process	Stream	Supply temperature [°C]	Target temperature [°C]	CP [MW/°C]	ΔH [MW]	Type of medium	h [MW/(m^2 °C)]
Process A	A1, cold	50	110	0.05	3.0	Liquid	0.0008
	A2, hot	100	30	0.06	4.2	Liquid	0.0008
	A3, cold	100	140	0.02	0.8	Gas	0.00035
Process B	B1, hot	190	120	0.06	4.2	Gas	0.00035
	B2, cold	100	240	0.04	5.6	Gas	0.00035
	B3, hot	80	60	0.02	0.4	Liquid	0.0008

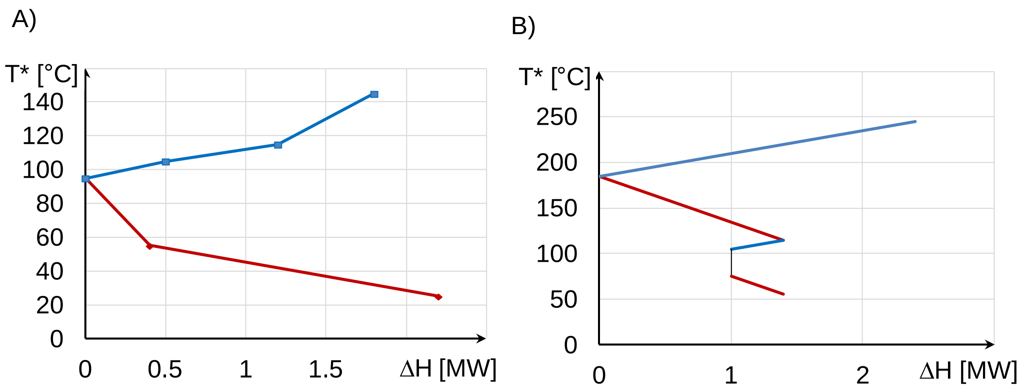


Figure 4: GCC of A) Process A and B) Process B

Three utilities are available. For cooling water is used with inlet temperature of 20 °C and outlet 30 °C, $h_{water} = 8\cdot10^{-4}$ MW/(m^2 °C). The intermediate utility is steam at 120 °C, $h_{LP\ steam} = 0.01$ MW/(m^2 °C) and the utility with the highest temperature is available at 250 °C, $h_{HP\ steam} = 0.011$ MW/(m^2 °C).

3.2 Results

First the heat recovery within the processes is estimated. Their GCCs are presented in Figure 4.

To evaluate the influence of heat recovery at Total Site level, the heat transfer area is first estimated without intermediate utility. Figure 5a shows the TSP for this case. In the next step, the heat recovery through the central utility system using an intermediate steam utility was considered. The TSP for this case is presented in Figure 5b.

Table 2: Comparison of the solution obtained when considering heat recovery through the intermediate utility

Total Site heat recovery	**Hot utility consumption [MW]**	**Cold utility consumption [MW]**	**Required Area [m^2]**
NO	3.66	3.6	1237.8
YES	2.66	2.6	1270.7

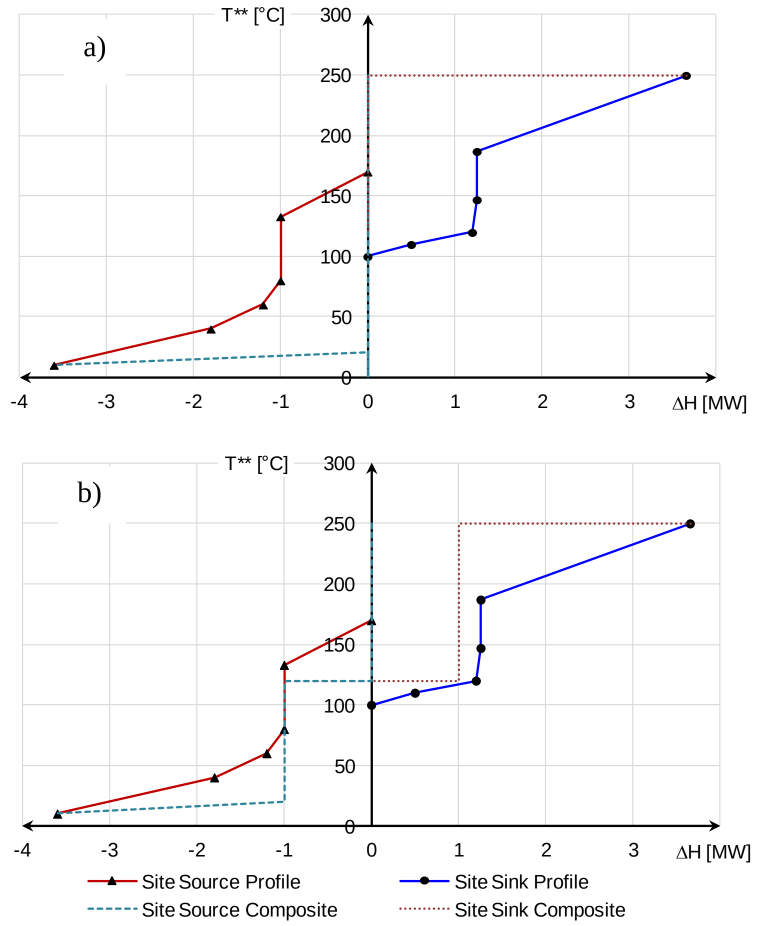


Figure 5: Total Site Profile a) without and b) with intermediate utility, considering heat recovery

The results are shown in Table 2, indicating that about 1 MW heat recovery can be obtained at the expense of increasing the heat transfer area by 32.9 m^2.

4. Conclusions

A procedure for evaluating the heat transfer area for a heat exchange between utility and process streams on a Total Sites has been developed and demonstrated. This enables a preliminary analysis of the trade-off between the amount of recovered heat and the needed investment cost at the Total Site level. In the presented case study 1 MW of heat can be recovered through the central utility system for which 32.9 m^2 additional heat transfer area is required. It indicates that the additional investment can be economically viable.

The developed model and the results lay out the ground for a procedure evaluating the capital cost targets for all heat transfer units on a Total Site in a future work – also including the heat recovery at the process level. Based on this, the capital energy trade-off can be evaluated and an optimisation of the minimum allowed temperature difference specifications for whole Total Sites can be performed.

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Nomenclature

ΔT_{min}	minimal temperature difference between two process streams, °C
ΔT_{minPU}	minimal temperature difference between process stream and utility, °C
EI	enthalpy interval, MW
PTA	Problem Table Algorithm
CP	heat capacity flowrate, MW/°C
A	area of heat exchanger, m^2
ΔT_{LM}	Logarithmic mean temperature, °C
Q	heat, MW
Q_k	heat exchanged in enthalpy interval k, MW
h	heat transfer coefficient, W/(m^2 °C)
h_U	heat transfer coefficient of the utility stream, W/(m^2 °C)
h_{jPR}	heat transfer coefficient of process stream, W/(m^2 °C)
ΔH	enthalpy, MW
T	temperature, °C
T*	shifted temperature, °C
T**	twice shifted temperature, °C
U	overall heat transfer coefficient, W/(m^2 °C)

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